High Redshift Galaxies (and ALMA)

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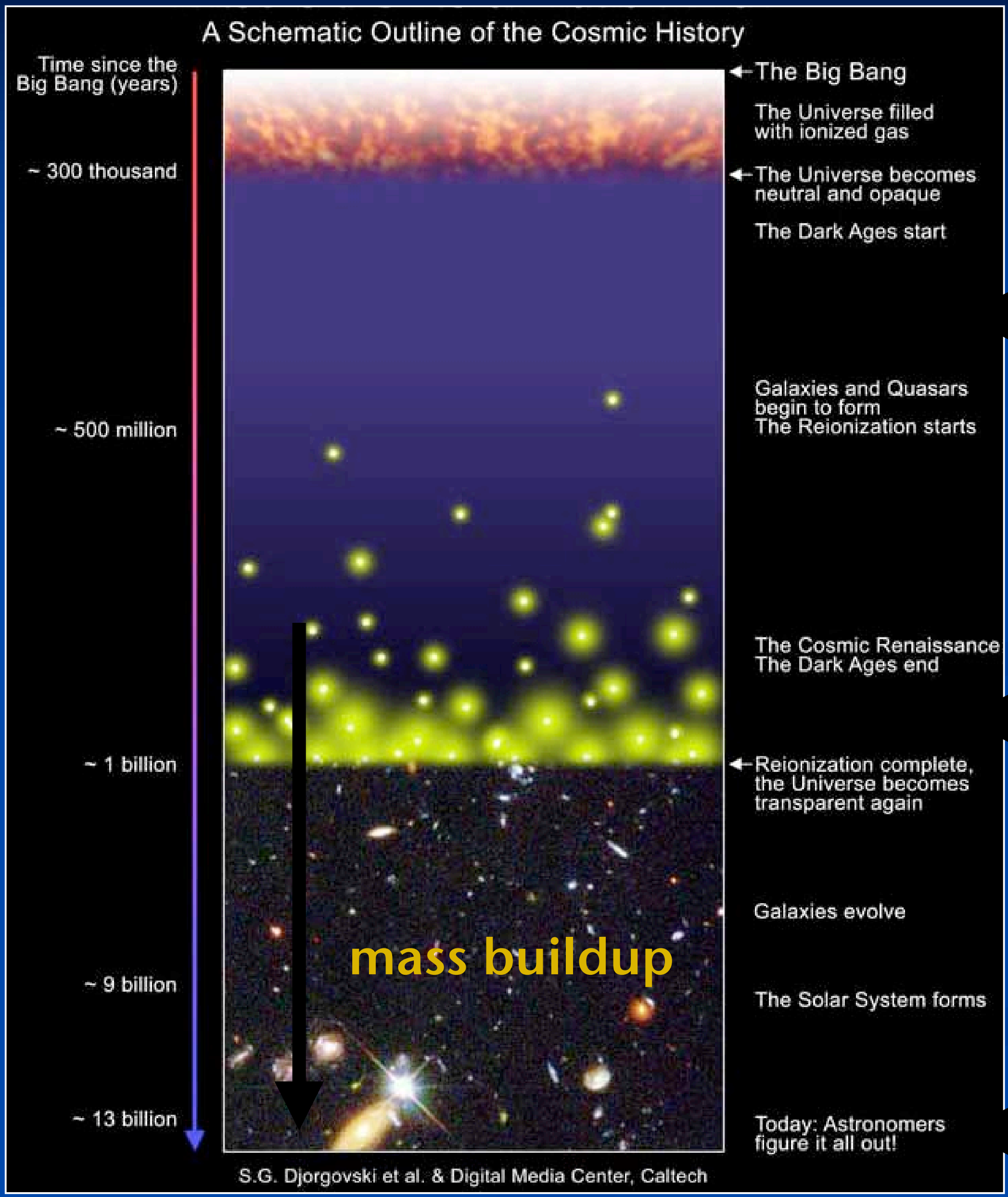
HISTORY OF THE UNIVERSE



Cosmic 'Dark Ages'
no stars/quasars

Epoch of
Reionization (EoR)

galaxies today

High Redshift Galaxies

• *high redshift galaxies:*

- Lyman Break galaxies
- Lyman α galaxies
- Submm ('SCUBA') galaxies
- Radio galaxies
- EROs
- faint blue galaxies
- QSO host galaxies

…

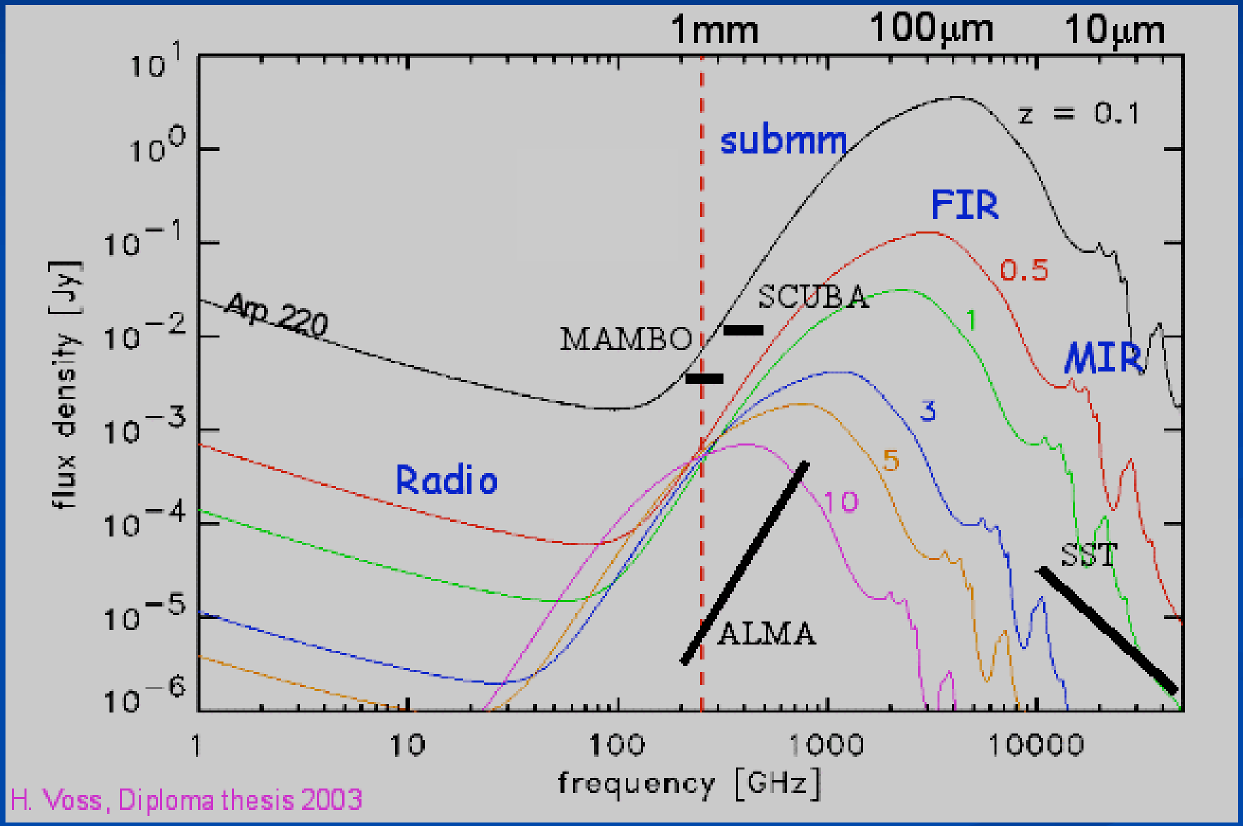
• *science drivers:*

- mass assembly / galaxy formation
- unified picture of galaxy evolution
- history of SFRD ('Madau plot') / stellar mass assembly
- evolution(?) of M_{BH}-σ relation

ALMA:

- detection/imaging of dust emission -> L_{FIR}
- detection/imaging of molecular lines
  - -> molecular gas ('SF reservoir')
  - -> dynamical masses

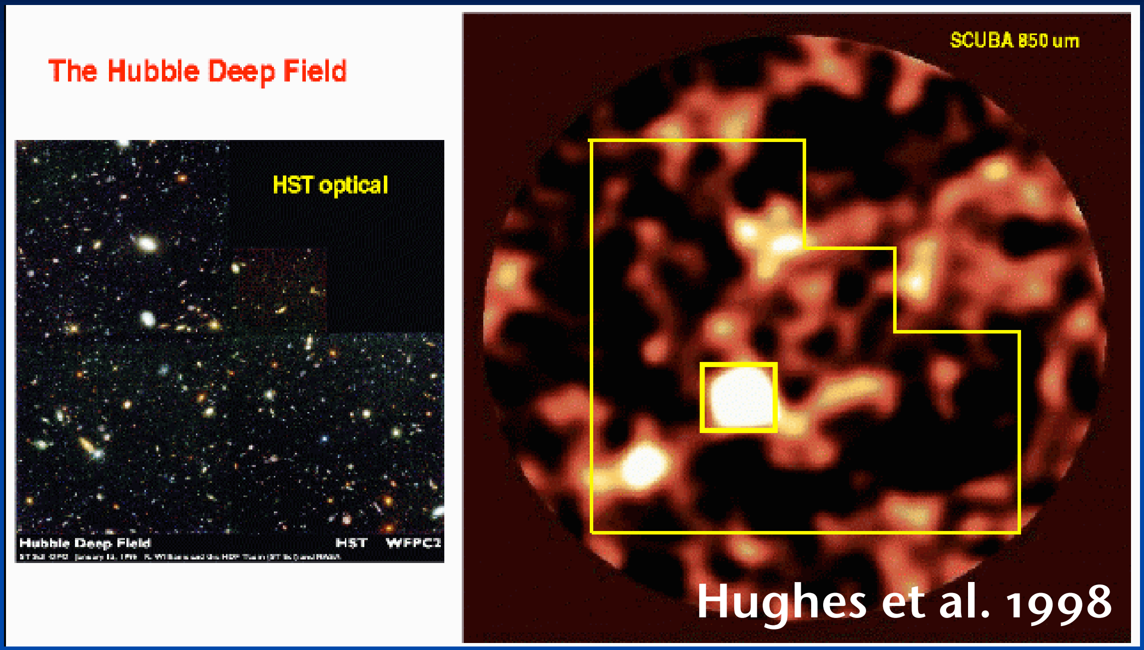
Dust Imaging: The Magic of (Sub-)mm

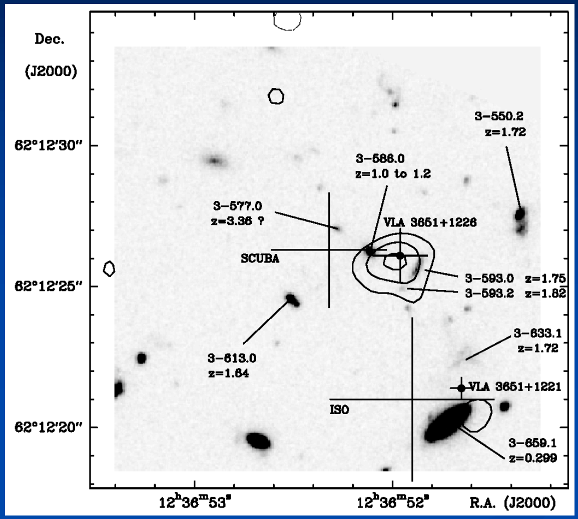


from Bertoldi, Voss

$L_{fir} = 4x10^{12}\ S_{250}(mJy)\ L_{sun}$

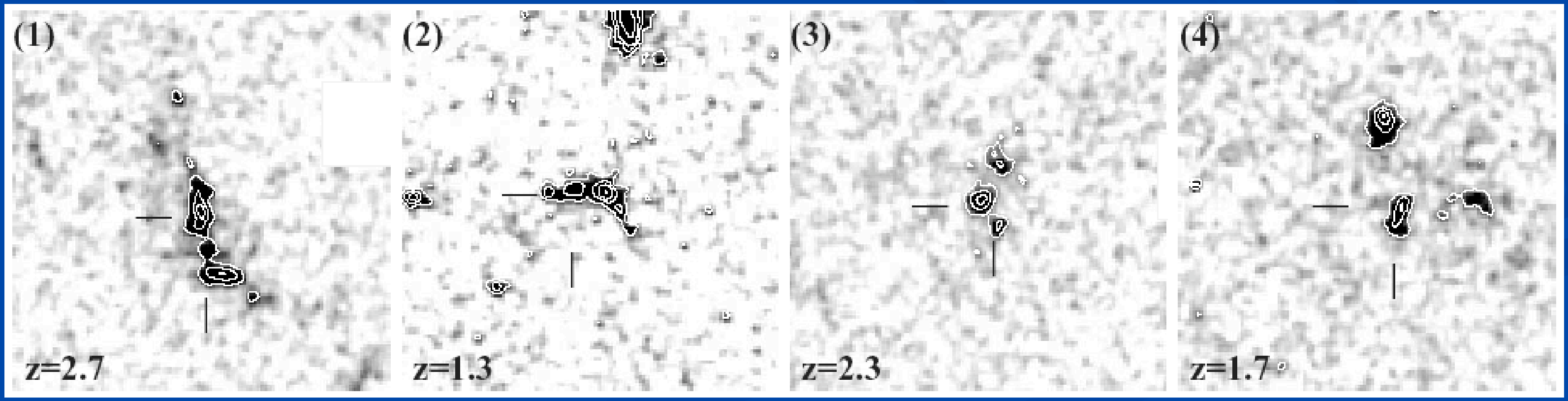
Submm ('SCUBA') Sources





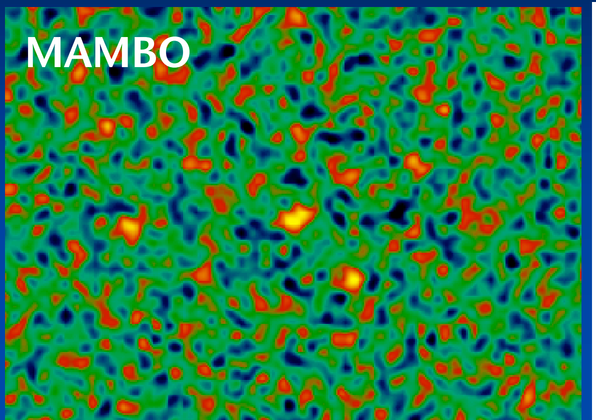
Downes et al. 1999

HST imaging (Chapman et al. 2003): irregular/complex -> mergers?



ALMA will map the dust in submm sources (1 hour rms: ~20 μJy)

Dust in J1148+5251 at z=6.4

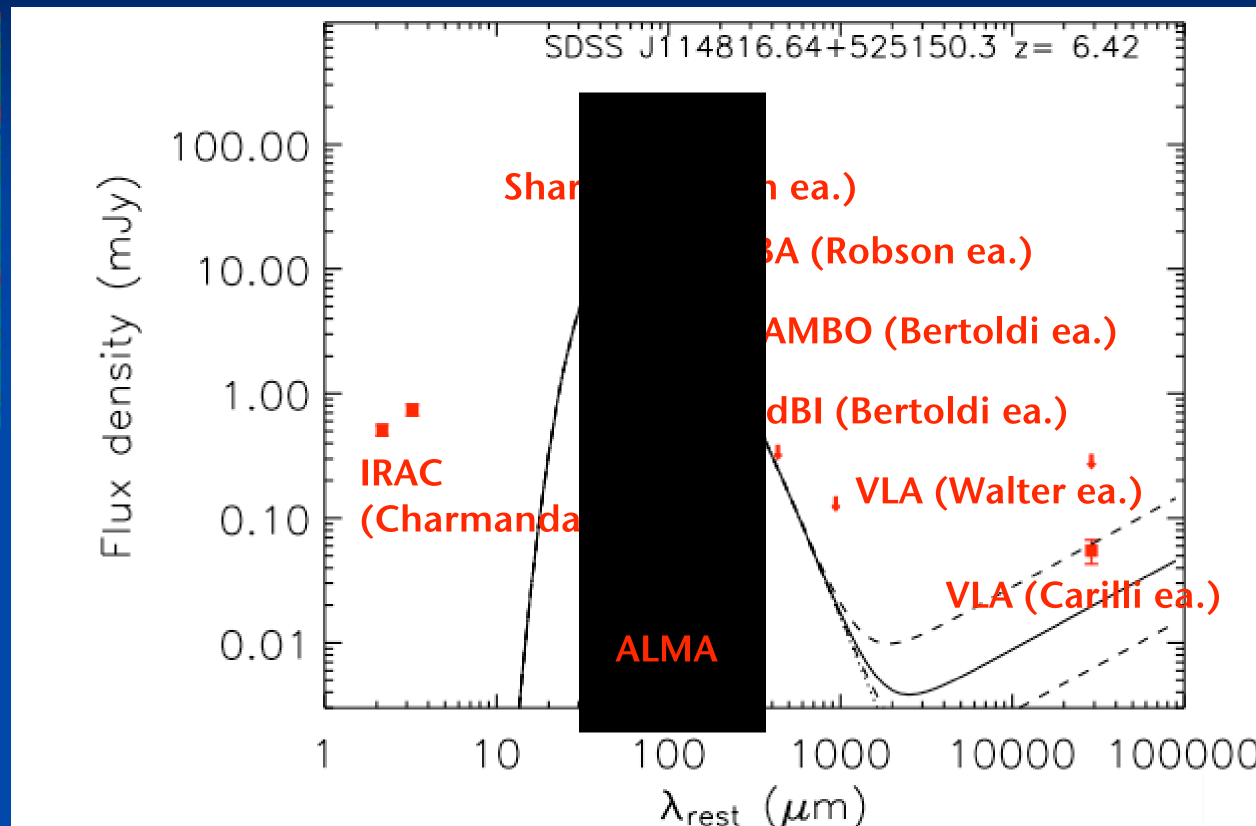


Bertoldi et al. 2004

$L_{FIR}=2\ 10^{13}\ M_{sun}$

SFR = 3000 $M_{sun}\ yr^{-1}$

combined starburst / AGN SED



Beelen, Cox et al. 2004

ALMA: 1 hour rms:

100 GHz 5 μJy

250 GHz 13 μJy -> 5σ = 65 μJy -> $3\ 10^{11}\ L_{sun}$

350 GHz 26 μJy

650 GHz 130 μJy

ALMA DRSP: - continuum survey:
rms 0.02 mJy (4’x4’, 80 hours)

Molecular Gas: Key to Galaxy Evolution

Object	Type	Redshift	CO J_u	Telescope	Reference (… et al.)
IRAS10214+4724	QSO*	2.28	3 6	12m 30m	Brown 1991, Solomon 1992
SMM J16368+4057	SMM	2.385	3 7	PdB	Neri 2003
53W002	QSO	2.39	3	OVRO PdB	Scoville 1997, Alloin 2000
SMM J04431+0210	SMM	2.509	3	PdB	Neri 2003
Cloverleaf	QSO*	2.558	3	PdB	Barvainis 1994
SMM J14011+0252	SMM*	2.565	3 7	OVRO PdB	Frayer 1999, Downes 2003
PSS J1409+5628	QSO	2.56	3	PdB	Beelen 2004
MG 0414-0534	QSO*	2.639	3	PdB	Barvainis 1998
MS1512-cB58	LBG*	2.72	3	PdB	Baker 2003
Q1230+1627B	QSO*	2.74	3	PdB	Guilloteau 1999
SMM J02399-0136	SMM*	2.808	3	OVRO PdB	Frayer 1998, Genzel 2003
B3 J2330+3927	RG	3.094	4	PdB	de Breuck 2003
MG 0751+2716	QSO*	3.20	4	PdB	Barvainis 2002
SMM J09431+4700	SMM	3.346	4	PdB	Neri 2003
TNJ0121+1320	RG	3.520	4	PdB	de Breuck 2003
6C1909+722	RG	3.534	4	PdB	Papadopoulos 2000
4C60.07	RG *	3.788	4	PdB	Papadopoulos 2000
APM 08279+5255	QSO*	3.911	4 9	PdB	Downes 1999
PSS J2322+1944	QSO*	4.119	12 45	PdB VLA Eb	Cox 2002, Carilli 2002
BRI 0952-0115	QSO*	4.43	5	PdB	Guilloteau 1999
BRI 1335-041	QSO	4.407	2 5	PdB VLA	Guilloteau 1997, Carilli 2002
BRI 1202-0725	QSO	4.69	12 45	PdB VLA Eb	Omont 96a, Ohta 96, Carilli 02
SDSS J1148+5251	QSO	6.419	3 67	VLA PdB	Walter 2003, Bertoldi 2003

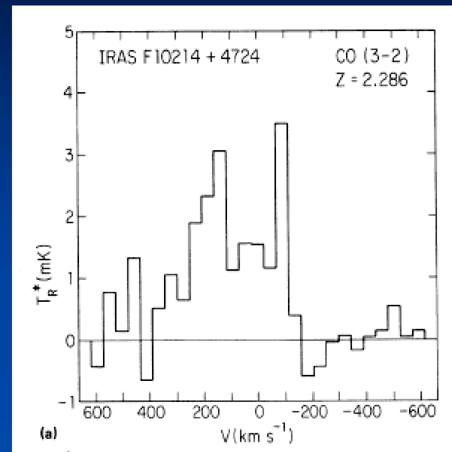
(*) definitely lensed, SMM=submm galaxy, RG=Radio Galaxy

13 QSO + 5 SMM + 4 RG + 1 LBG = 23

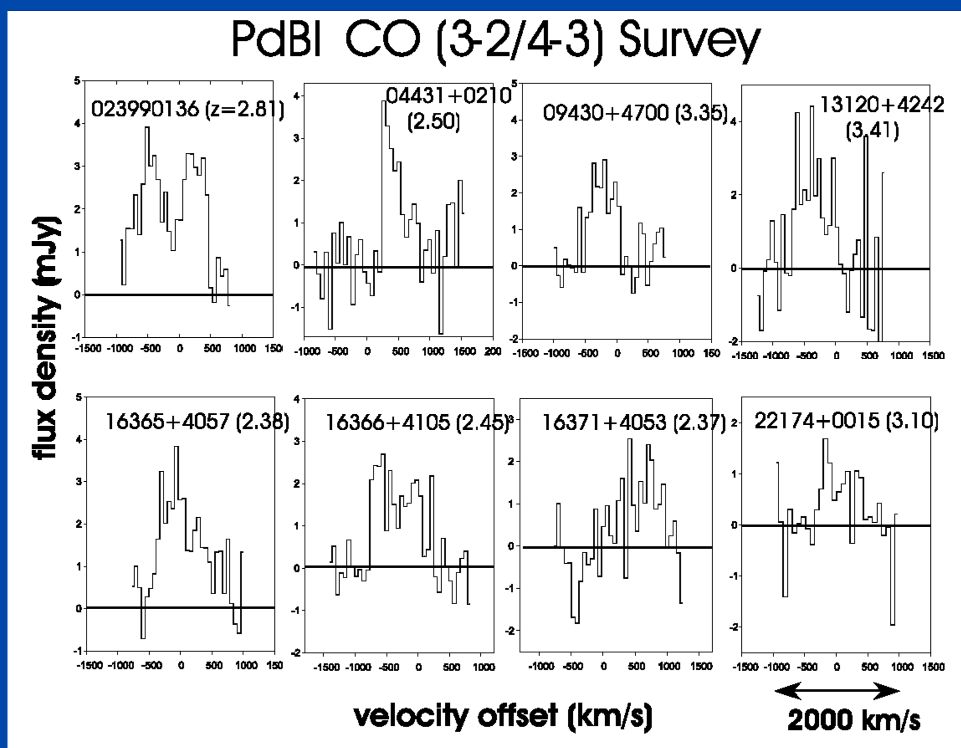
CO in Submm Sources

IRAS 10214+4724

1st CO detection at z>>0



Brown & Vanden Bout 1991



bright SMGs have

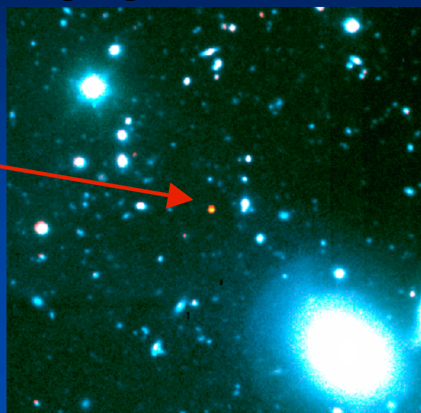
large dynamical masses

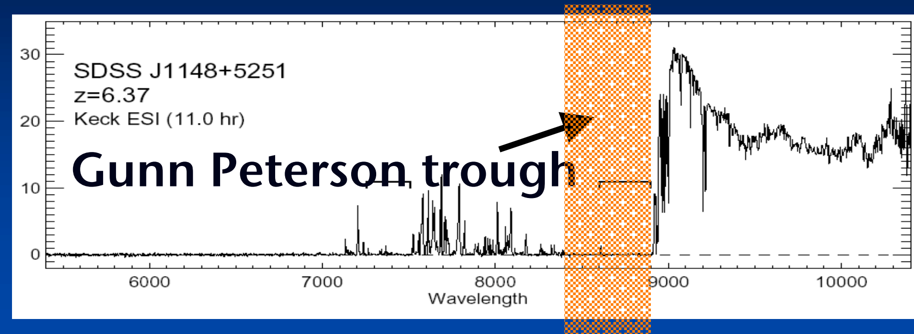
Neri et al. 2003,
Greve et al. 2004

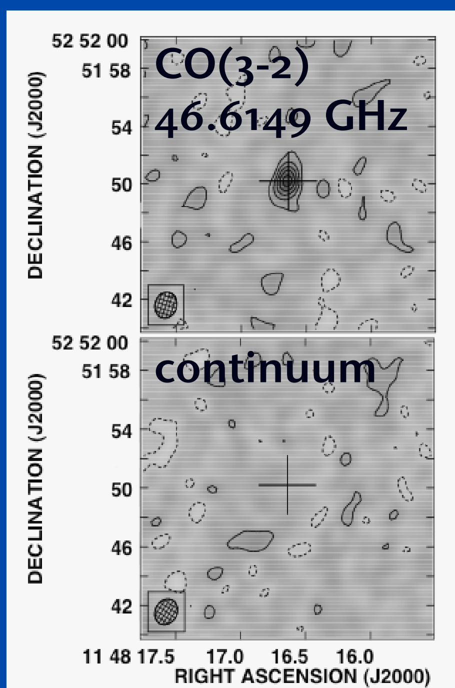
Genzel et al. 2004

CO IN QSO HOST @ z=6.42

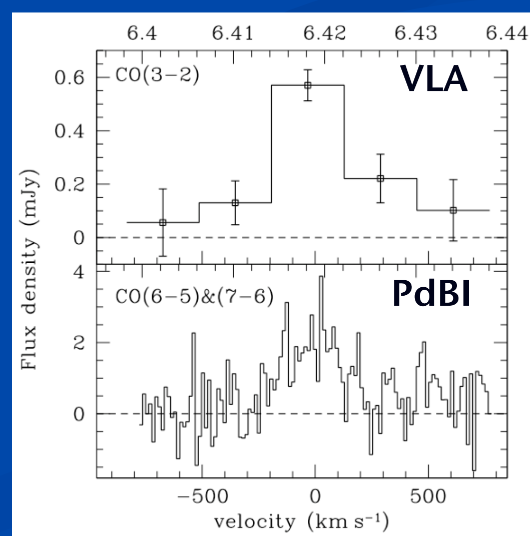
J1148+5251







- 800 Myr after BB, in EoR
- host galaxy(!)
- mol. gas mass: $M_{H_2} = 2\ 10^{10}\ M_{sun}$



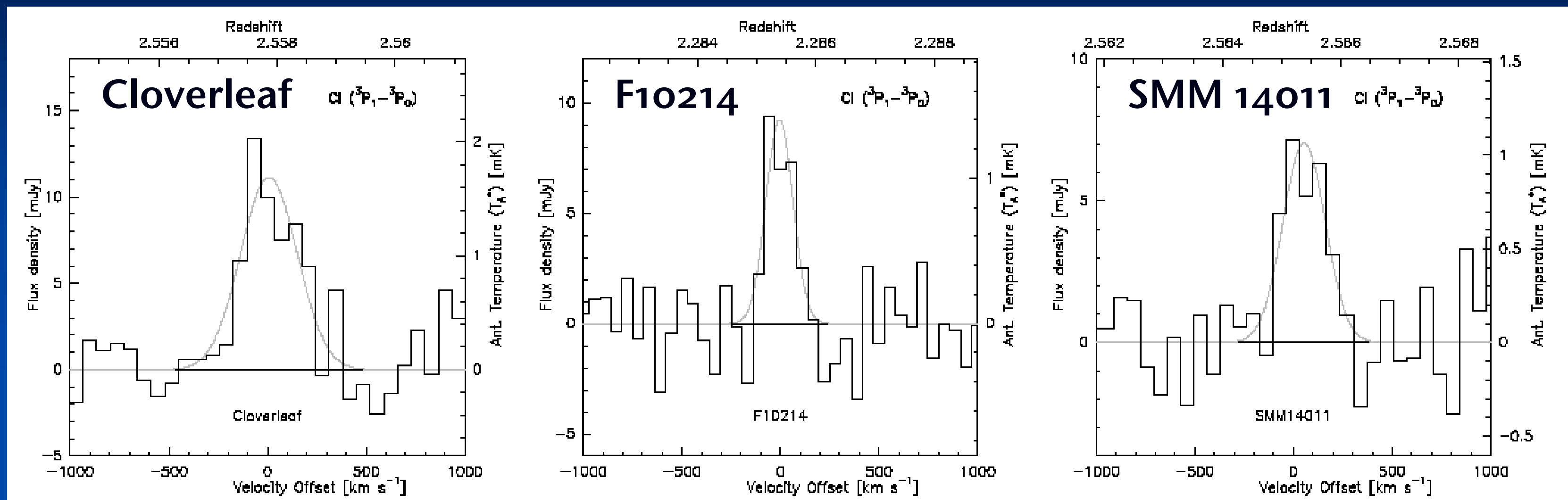
T_{kin}=80 K,

$n_{H_2}=10^{4.5}\ cm^{-3}$

Walter et al. 2003
Bertoldi et al. 2003

Other Tracers: CI and HCN at z~2.5

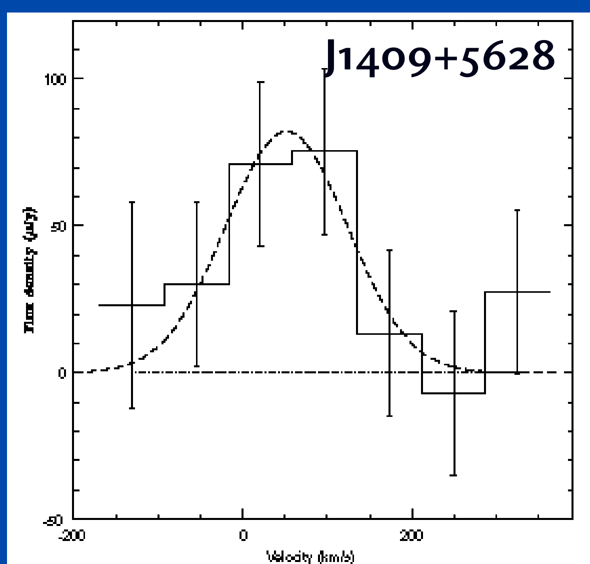
CI
@z=2.5



-> T_{ex}, carbon abundance

Weiss, Henkel, Downes & Walter 2004

HCN
@z=2.6

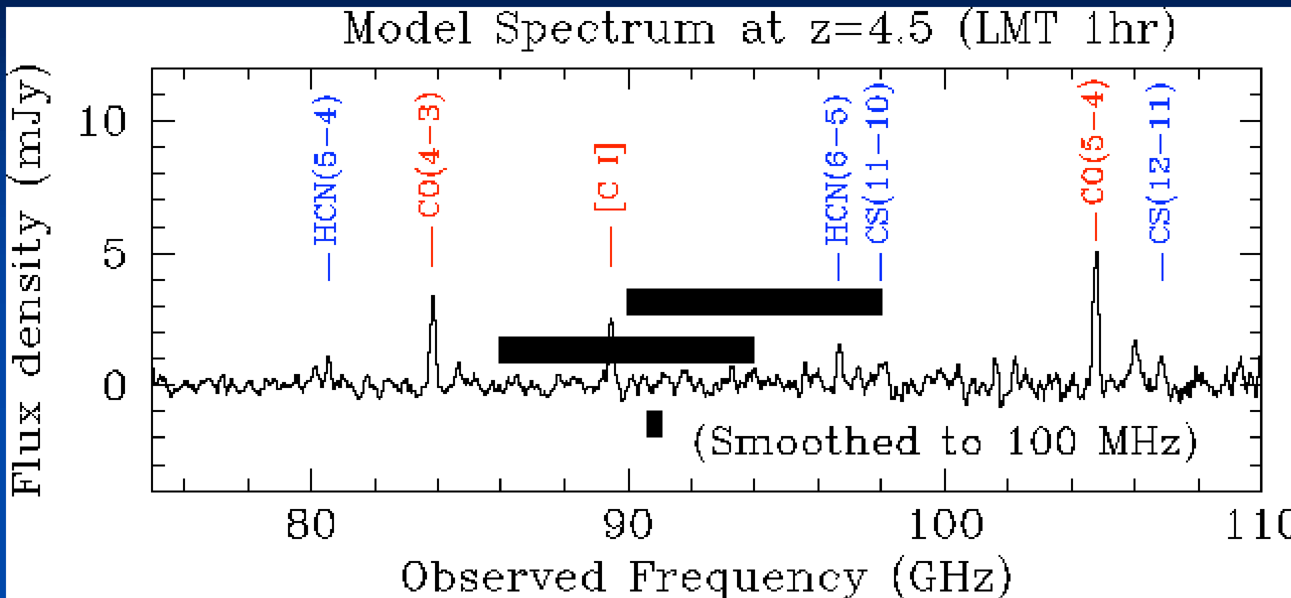


M_{H_2}=1 10^{10} M_{sun}

signature of
dense starforming
molecular gas

Carilli, Solomon, vanden Bout, Walter et al. 2004

MULTIPLE LINES IN ONE GO



LMT simulations (from Yun)

- fractional BW:

VLA:

- 50MHz/40GHz=0.001

PdBI:

- 500Mhz/100GHz=0.005

ALMA:

- 8GHz/100GHz=0.08
- 8GHz/350GHz=0.02

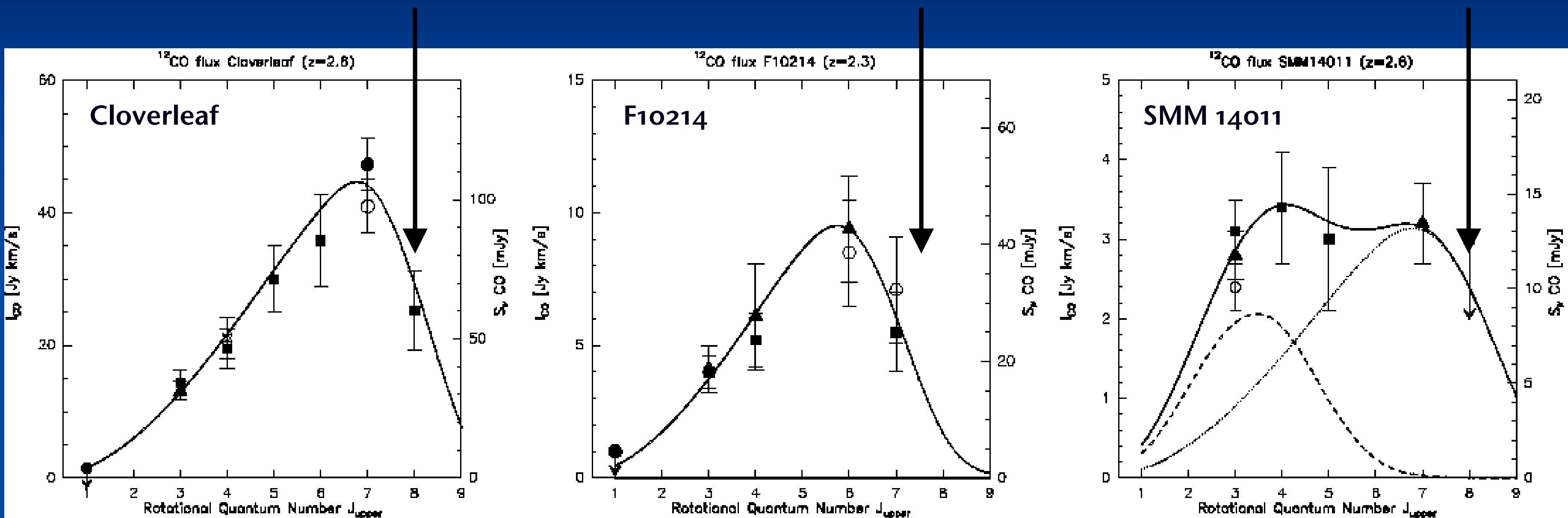
DRSP:

4 settings from 84-116 GHz
in 4’x4’ field (256 hours)
-> continuum plus
- at least one CO line: z>2
- two CO lines: z>6

5 σ detection limit: 0.04 Jy kms^{-1}

[current CO(3-2): 0.2 - 10 Jy km s^{-1}]

CO Ladders ('CO SEDs')



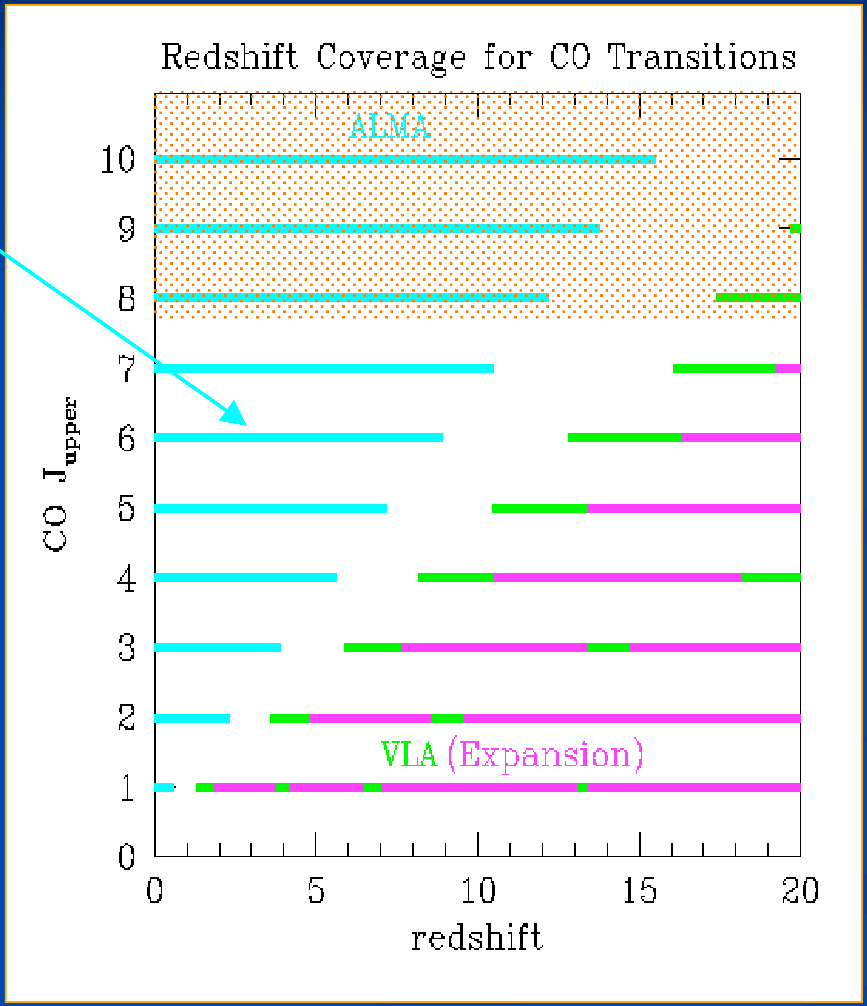
temperatures/densities similar to nearby SB centers

CO ladders: difficult to do CO transitions > (7-6)

Weiss, Walter et al. 2004

ALMA Redshift Coverage

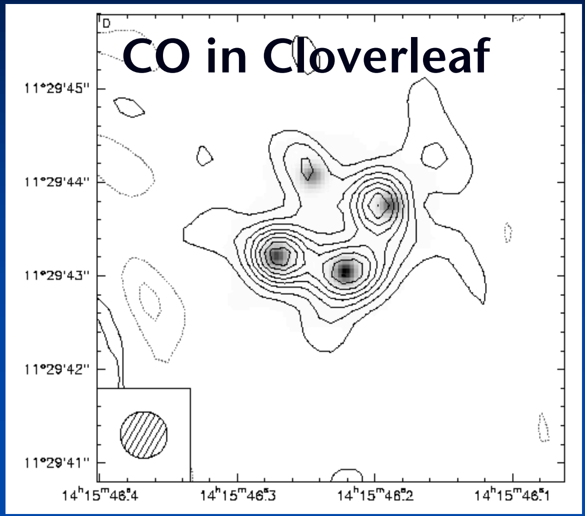
ALMA



Resolved CO Emission

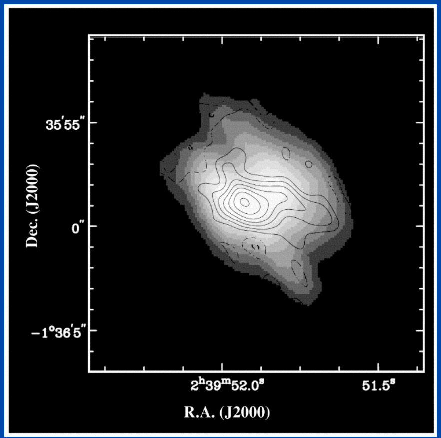
Ultimate goal:

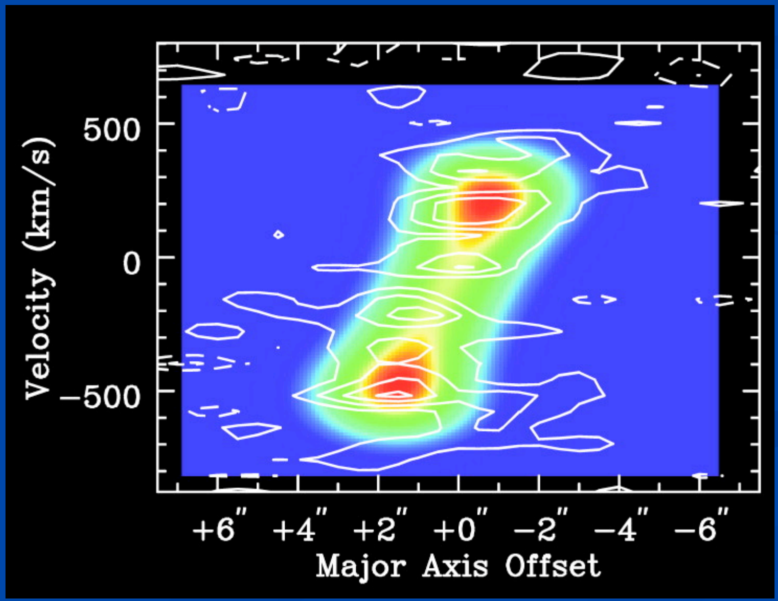
Resolve CO emission spatially/kinematically
- compare to optical/NIR imaging
- dynamical masses!



Alloin et al. 1997

SMM J02399-0136





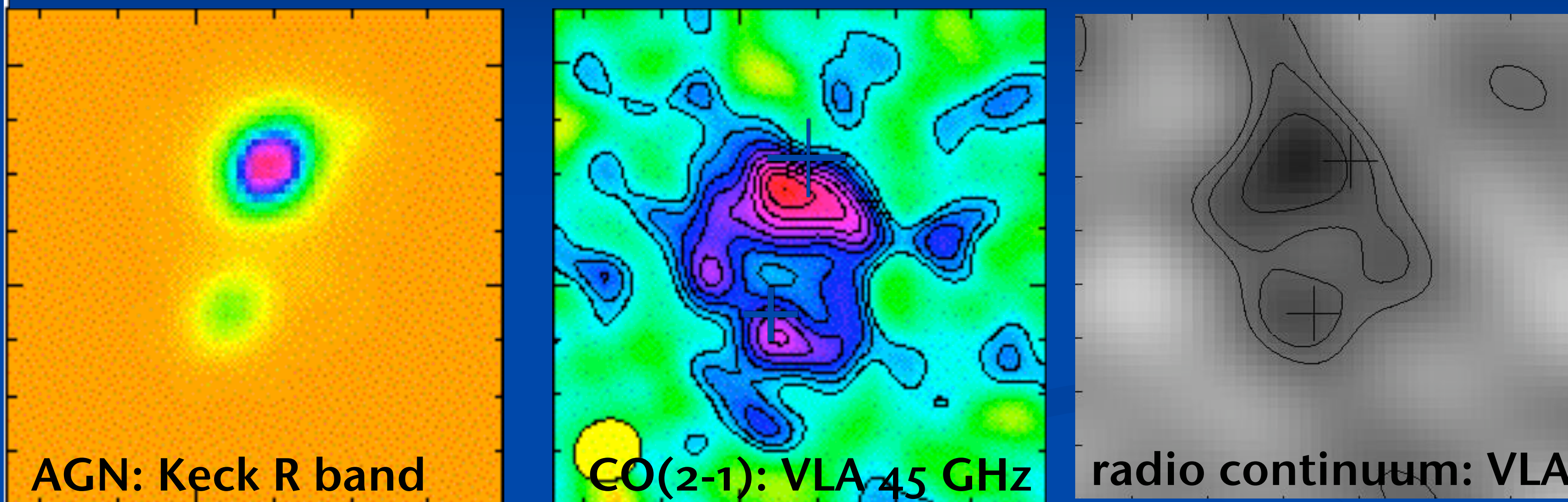
Genzel et al. 2002

r~8 kpc

$M_{dyn} > 3\ 10^{11}\ M_{sun}$

SF Disk Around QSO at z=4.12

J2322+1922: Lensed QSO at z=4.12



Carilli et al. (2003)

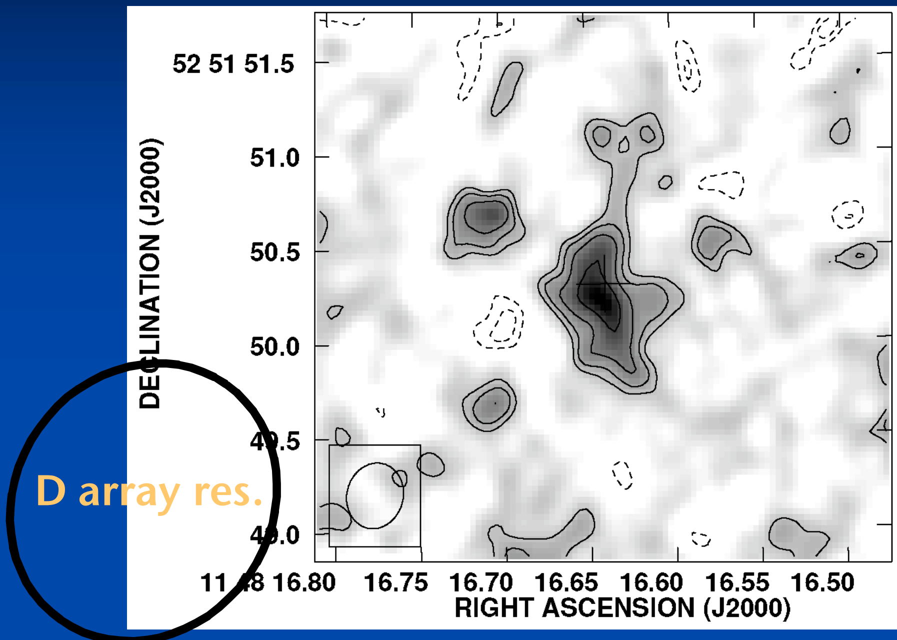
Molecular Einstein Ring:

RC *cospatial* w/ Gas, not AGN, r ~ 2kpc

⇒ dust emission heated by SF *not* AGN, SFR~3000 $M_{sun} yr^{-1}$ (!)

RESOLVED CO @ z=6.4

~80 hours VLA B + C array; res.: 0.3" (~2 kpc), rms 43μJy



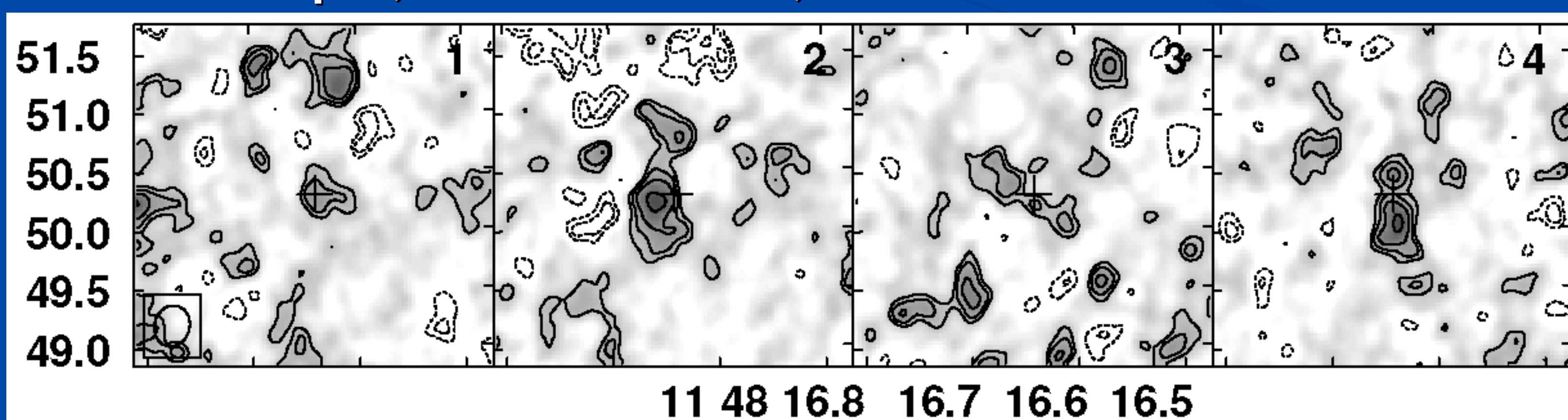
- assuming disk geometry:
  b_{maj}=3.6 kpc, v_{rot}=280 kms^{-1}
  M_{dyn}~ 6 x 10^{10} M_{sun}

M_{BH}=3 10^9 M_{sun} ->

M_{bulge} = few 10^{12} M_{sun}?

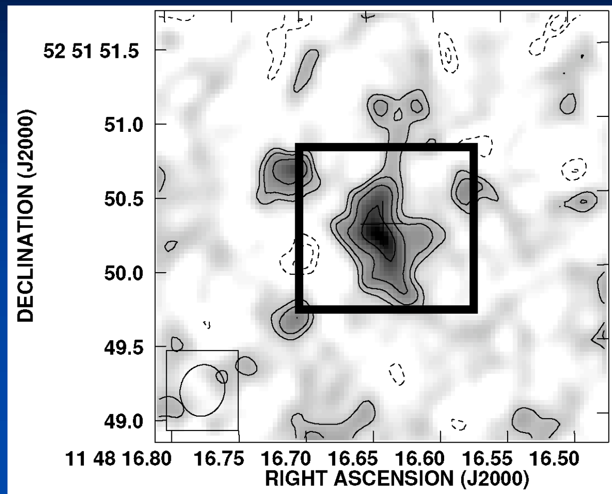
M_{BH}-σ breakdown?

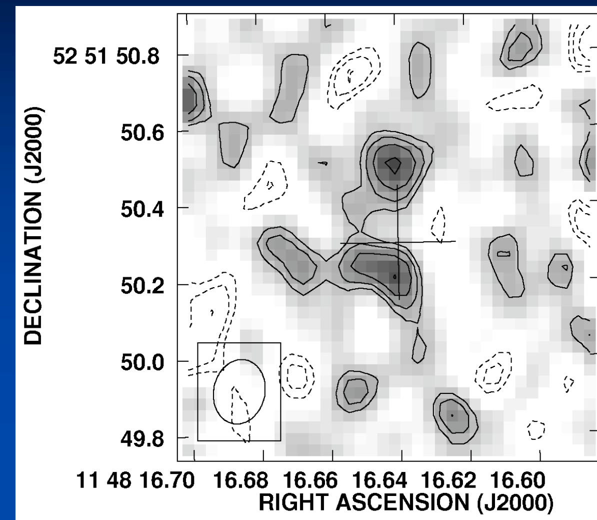
channel maps (width: 60 km s^{-1}):



Walter et al. 2004

CO @ 1kpc Resolution





Walter et al. 2004

- $M_{H_2}=5 \times 10^9\ M_{sun}$, $T_B(z=6.4)=35$ K

[~nearby SB centres, but size is 10 times larger]

-> need ~0.15" resolution to get 1 kpc resolution
[1"=8.5 kpc @ z=2, 1"=5.8 kpc @ z=6]

z=6.5 CO(7-6): 100 GHz (band 3): 4 km baselines
z=2.5 CO(3-2): 100 GHz (band 3): 4 km baselines
CO(6-5): 230 GHz (band 6): 1.8 km baselines

SUMMARY

- massive reservoirs of molecular gas detected out to EoR.
  ALMA will - image dust emission out to highest z
  - image CO emission out to highest z
  ALMA could - see sources out to z>10
  - detect L_{FIR}~10^{11} L_{sun} out to z=10

- CO: early metal enrichment, dynamical masses

- so far we have only looked at the tip of the iceberg - rapidely evolving field

-> ALMA will provide unified picture of galaxy evolution